χ_{c2} Formation in Two-Photon Collisions in L3

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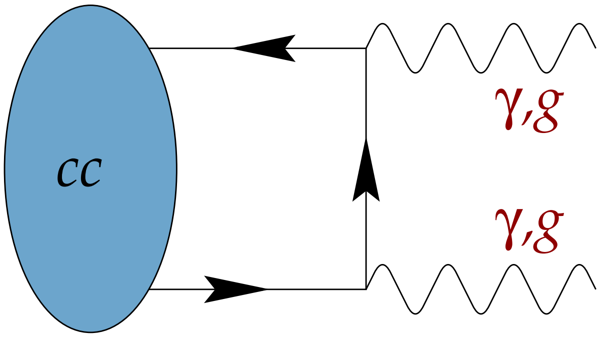
Charm Decays

Decays of $c\bar{c}$ pairs into gg, $\gamma\gamma$:
separate perturbative and non-perturbative effects



$$\frac{\Gamma(c\bar{c} \to gg)}{\Gamma(c\bar{c} \to \gamma\gamma)} = \frac{9}{8}\left(\frac{\alpha_s}{\alpha}\right)^2$$

associated with decays of charmonium resonances into $\gamma\gamma$, (light) hadrons.

Account for $c\bar{c}g$ content in χ_c states:
spin-independent $\Gamma(\chi_c \to ggg) \approx \Gamma(\chi_{c1} \to \text{hadrons}) \Rightarrow$

$$\frac{\Gamma(\chi_{c2} \to \text{hadrons}) - \Gamma(\chi_{c1} \to \text{hadrons})}{\Gamma(\chi_{c2} \to \gamma\gamma)} = \frac{9}{8}\left(\frac{\alpha_s}{\alpha}\right)^2$$

Include (sizeable!) NLO corrections;
Insert measured hadronic widths, $\alpha_s(m_c) = 0.25 \pm 0.02$:

$$\Gamma(\chi_{c2} \to \gamma\gamma) = 0.55 \pm 0.12\ \text{keV}$$

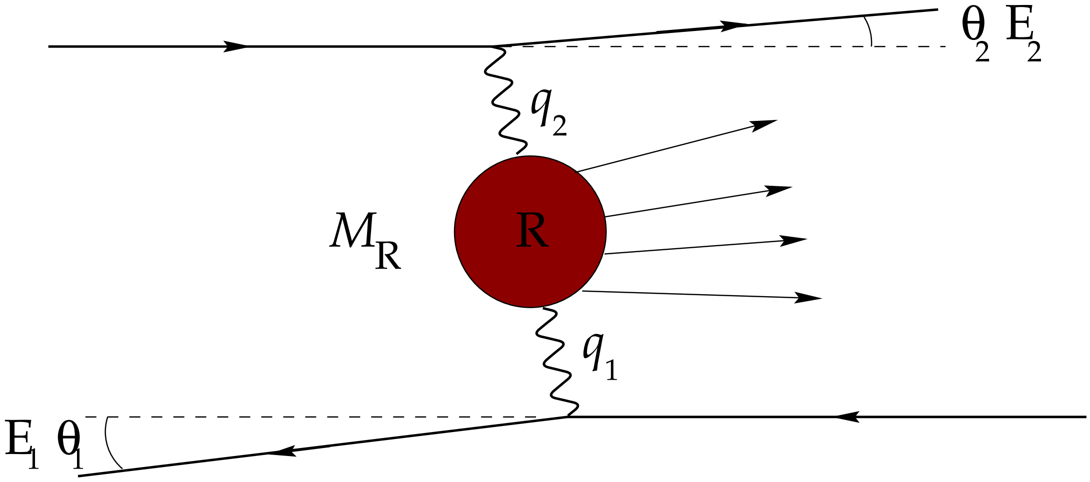
cf. 1.4 ± 0.2 keV in ‘naive’ model

Other predictions (sum rules):

$$\Gamma(\chi_{c2} \to \gamma\gamma) \simeq 0.5 - 2\ \text{keV}$$

Two-Photon Production

Resonance production in $\gamma\gamma$ collisions:
Production of $C = +$ states, with $J \neq 1$ for quasi-real photons.



$$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^- R) = \int \sigma_{\gamma\gamma\to R}(W^2_{\gamma\gamma}) d\mathcal{L}_{\gamma\gamma}(W^2_{\gamma\gamma}),$$

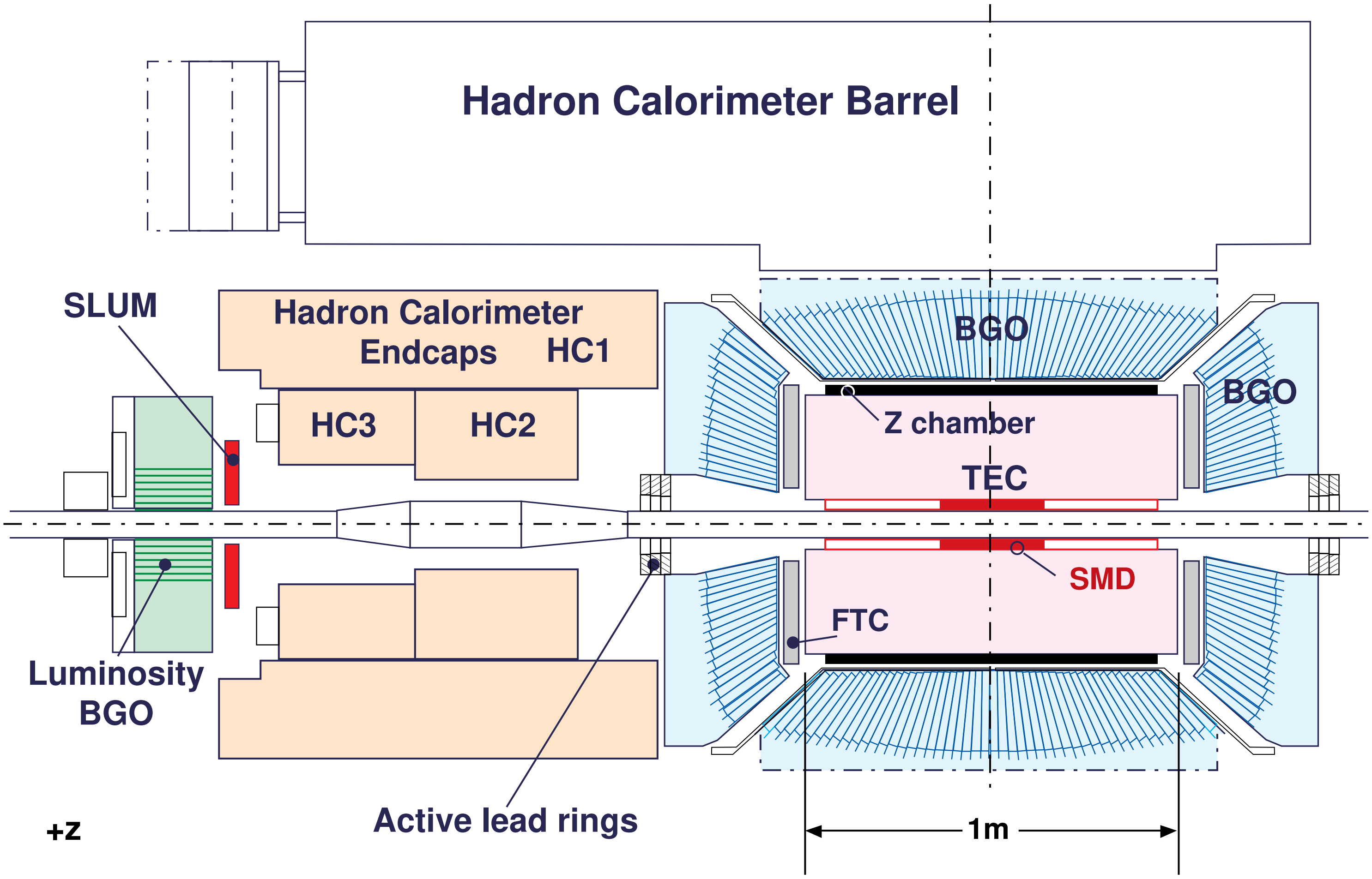
with

$$\sigma_{\gamma\gamma\to R}(W^2_{\gamma\gamma}) = 8\pi \frac{(2J_\mathrm{R}+1)\Gamma^\mathrm{R}_{\gamma\gamma}}{M_\mathrm{R}} \cdot \frac{M_\mathrm{R}\Gamma_\mathrm{R}}{(W^2_{\gamma\gamma} - M^2_\mathrm{R})^2 + M^2_\mathrm{R}\Gamma^2_\mathrm{R}}$$

Measure $\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\chi_{c2}) = \mathcal{K}\Gamma(\chi_{c2} \to \gamma\gamma)$

This presentation: identification of χ_{c2} state by decay $\chi_{c2} \to \gamma\,\mathrm{J}/\psi$, $\mathrm{J}/\psi \to \ell^+\ell^-$ where $\ell = \mathrm{e}, \mu$.
Data: 142pb^{-1} from 1991-1995

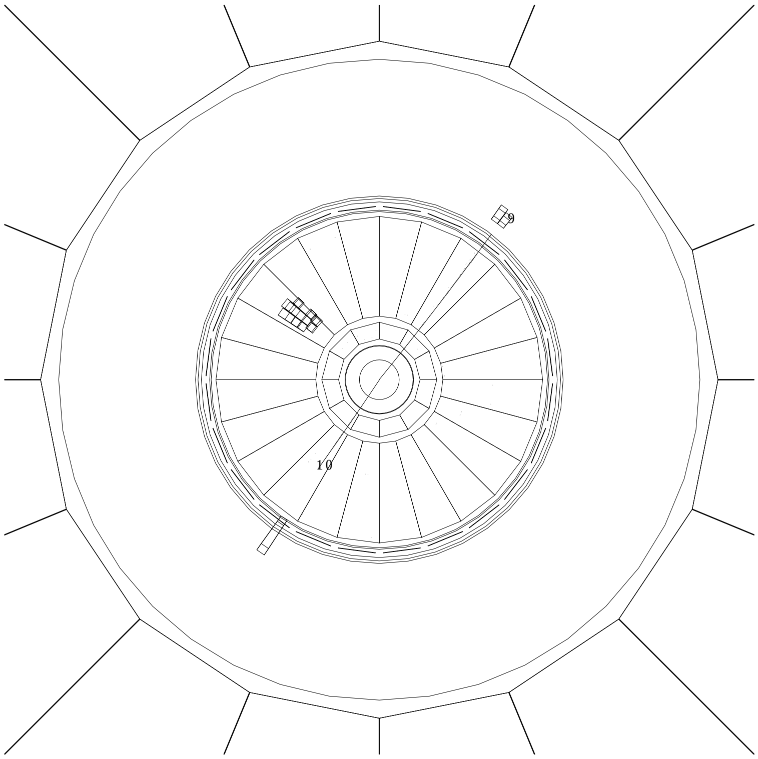
Event Selection

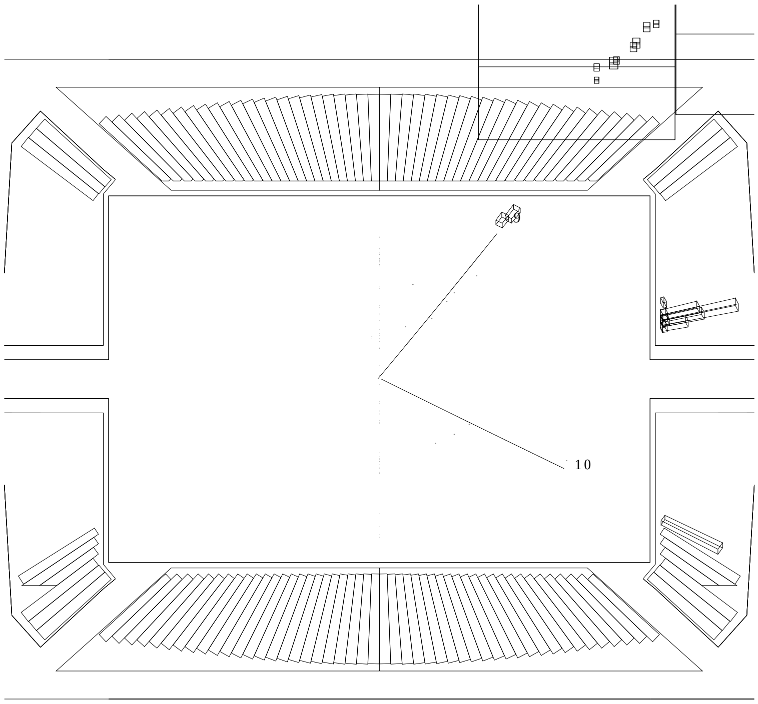


Detectors used:

- TEC: $\Delta p_t/p_t = 0.018 p_t$
- ECAL: $\Delta E/E = 0.0154/\sqrt{E} + 0.0038$
- LUMI: $1 < Q^2 < 10~\mathrm{GeV}^2$

Event Selection

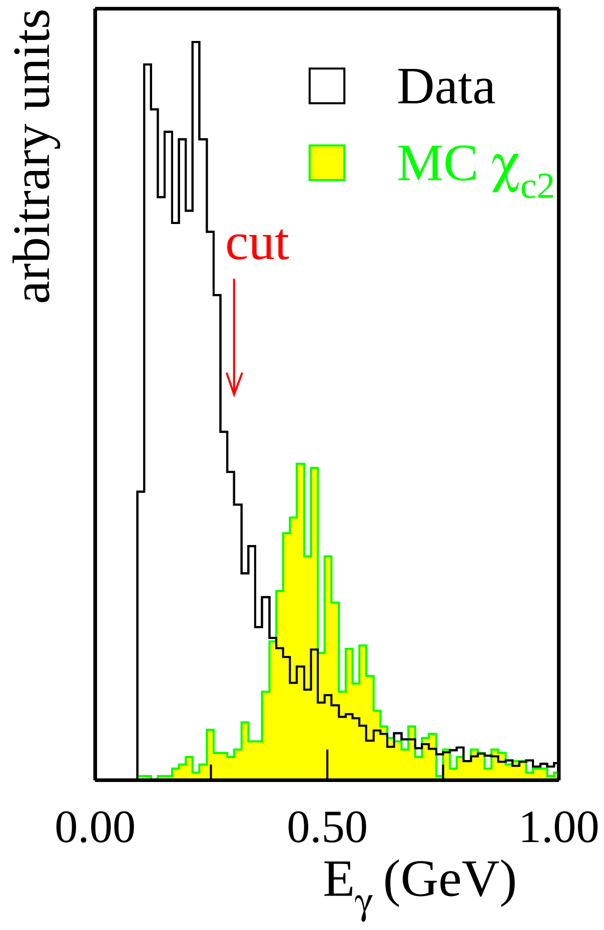


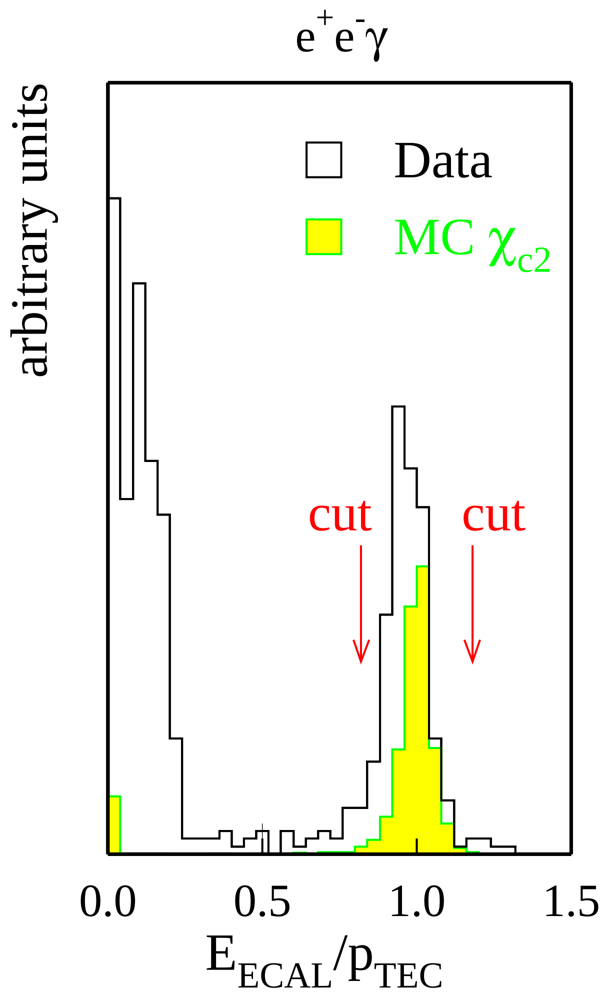


Event Selection

Selection criteria for $\ell^+\ell^-\gamma$ final states:

- 1 photon with $E_\gamma > 300\mathrm{MeV}$;
- Missing transverse momentum $P_t^2 < 0.04\ \mathrm{GeV}^2$ (include tags with $E_{\mathrm{tag}} > 0.5E_{\mathrm{beam}}$);
- For $\mu^+\mu^-\gamma$ states: recognise μ as MIP in ECAL;
- For $\mathrm{e}^+\mathrm{e}^-\gamma$ states: energy/momentum match;
- $|M_{\ell^+\ell^-} - M_{\mathrm{J}/\psi}| < 250\ \mathrm{MeV}$





Efficiency

Monte Carlo simulation of signal:

- Consider only dominant $\sigma^{\rm TT}(\gamma\gamma \to \chi_{c2})$ contribution
- Produce χ_{c2} in helicity-2 state
- Apply form factors to χ_{c2} production:

$$F = \left(1 - q_1^2/M_{\rm V}^2\right)^{-1} \left(1 - q_2^2/M_{\rm V}^2\right)^{-1}$$

  with $M_{\rm V} = M_{{\rm J}/\psi}$
- Use decay helicity amplitudes (w.r.t. ${\rm J}/\psi$ direction) measured by E760

Trigger efficiency:

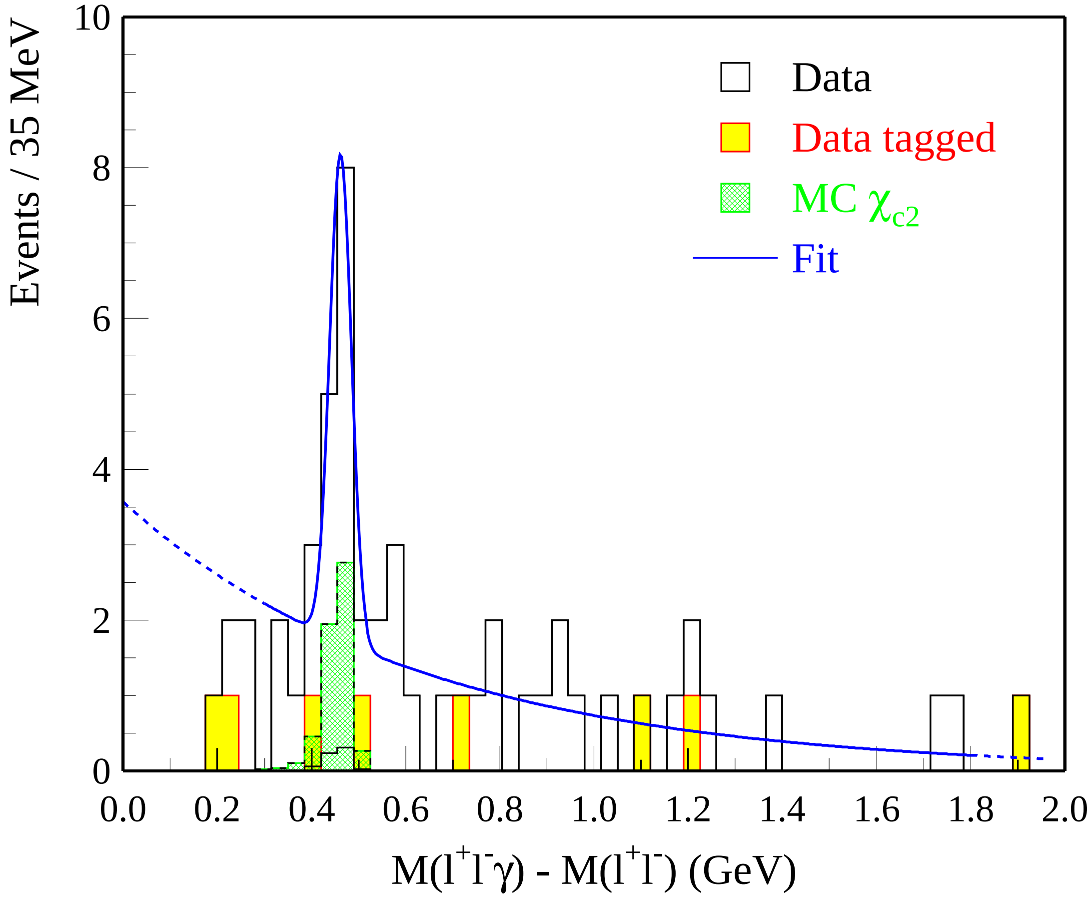
Charged-track trigger efficiency measured in ${\rm Z} \to {\rm e^+e^-}$ decays and checked in ${\rm e^+e^-} \to {\rm e^+e^-}\ell^+\ell^-$ events $\simeq$ 73%

Resulting efficiency:

- $\mu^+\mu^-\gamma$ states: 8.8%
- ${\rm e^+e^-}\gamma$ states: 6.3%
- weighted: $\epsilon = 7.6\%$

Results and Systematics Checks

Fit to $M_{\ell^+\ell^-\gamma} - M_{\ell^+\ell^-}$ distribution:



Fit background to J/ψ sidebands
(2.4 GeV $< M_{\ell^+\ell^-} <$ 2.8 GeV, 3.4 GeV $< M_{\ell^+\ell^-} <$ 3.8 GeV)

Fit gaussion to signal, with resolution fixed to MC value of 23MeV

Result: $N_{\text{events}} = 10.6 \pm 4.1$, $\Delta M_{\text{peak}} = 461 \pm 10$ MeV (exp: 459MeV)

Fitting background directly to $M_{\ell^+\ell^-\gamma} - M_{\ell^+\ell^-}$ distribution gives compatible results

Results and Systematics Checks

Systematic uncertainties:

Expect resonant background from χ_{c0} only:

$$N_{\chi_{c0}}/N_{\chi_{c2}} = \frac{1}{5}\frac{\Gamma(\chi_{c0} \to \gamma\gamma)}{\Gamma(\chi_{c2} \to \gamma\gamma)} \cdot \frac{\mathrm{B}(\chi_{c0} \to \gamma \mathrm{J}/\psi)}{\mathrm{B}(\chi_{c2} \to \gamma \mathrm{J}/\psi)} \cdot \epsilon_0/\epsilon_2 \simeq 3\%$$

Other Uncertainties:

χ_{c2} formation σ^{TT}	5%
χ_{c2} formation $\lambda = 2$	5%
J/ψ form factor	10%
χ_{c2} decay helicity	10%
$\mathrm{B}(\chi_{c2} \to \gamma \mathrm{J}/\psi)$	8%
Trigger efficiency	10%
Event selection	10%
Total	23%

Using $\mathcal{L} \approx 142\mathrm{pb}^{-1}$:

$$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\chi_{c2}) = \frac{N_{\mathrm{events}}}{\epsilon \mathcal{L} \mathrm{B}(\chi_{c2} \to \ell^+\ell^-\gamma)} = 61 \pm 24 \pm 14\mathrm{pb}$$

Calculate $\Gamma(\chi_{c2} \to \gamma\gamma) = \Gamma^{\mathrm{MC}}(\chi_{c2} \to \gamma\gamma) \dfrac{\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\chi_{c2})}{\sigma^{\mathrm{MC}}(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\chi_{c2})}$:

$$\Gamma(\chi_{c2} \to \gamma\gamma) = 1.5 \pm 0.6 \pm 0.3 \text{ keV}$$

Discussion

Using $142\mathrm{pb}^{-1}$ of data from 1991-1995, we determine

$$\Gamma(\chi_{c2} \to \gamma\gamma) = 1.5 \pm 0.6 \pm 0.3 \text{ keV}$$

Comparison with other experiments:

E760	$(p\bar{p} \to \chi_{c2} \to \gamma\gamma)$:	$\Gamma(\chi_{c2} \to \gamma\gamma) = 0.32 \pm 0.08 \pm 0.05$ keV
TPC/2γ	$(\mathrm{e^+e^-} \to \mathrm{e^+e^-}\chi_{c2})$:	$\Gamma(\chi_{c2} \to \gamma\gamma) = 3.4 \pm 1.7 \pm 0.9$ keV
CLEO	$(\mathrm{e^+e^-} \to \mathrm{e^+e^-}\chi_{c2})$:	$\Gamma(\chi_{c2} \to \gamma\gamma) = 1.08 \pm 0.30 \pm 0.26$ keV
$\mathrm{e^+e^-} \to \mathrm{e^+e^-}\chi_{c2}$ combined:		$\Gamma(\chi_{c2} \to \gamma\gamma) = 1.22 \pm 0.27$ keV

Inconsistencies between experiments?

Not enough statistics to discriminate between available models

Looking forward to increased statistics at LEP2!